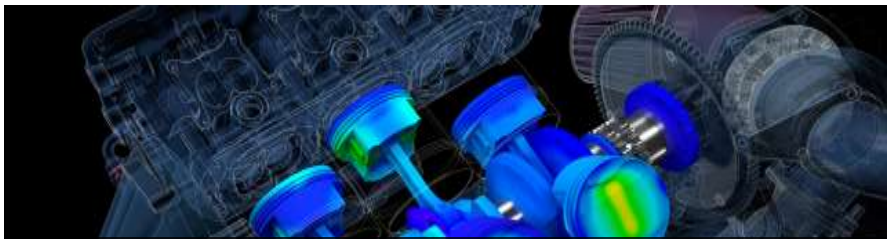


Transient and Conformal Mold Cooling Simulation

Franco Costa
Senior Research Leader

Parker Wright
Application Engineer

Class Summary

- In this class we will look at the Cool (FEM) capability in Autodesk Moldflow Insight and use it to study the way mold temperature changes during each molding cycle. We will also look at how new conformal cooling channels designs, including complex 3D shaped channels can be simulated using Autodesk Simulation CFD

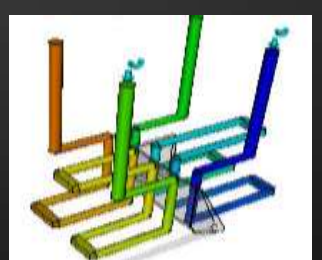
Learning Objectives

At the end of this class, you will be able to:

- ✓Set up a transient and conformal mold cooling analysis in Autodesk Moldflow Insight
- ✓Understand the theory and assumptions that underpin a transient mold cooling analysis
- ✓Simulate the new dynamic mold temperature control processes in injection molding
- ✓Understand the validation molding case studies performed to benchmark the "Cool (FEM)" technology

Transient and Conformal Mold Cooling Simulation

- Review
  - Theory
  - Analysis Options
  - 3D Mold meshing
  - Results
  - Validation Examples
- Updates in Scandium Tech Preview
- Rapid Heat Cycling
- Enhanced Heater Options
- Mold Meshing Enhancements
- Conformal Cooling



Temperature Equation

$$\rho C_P \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T)$$

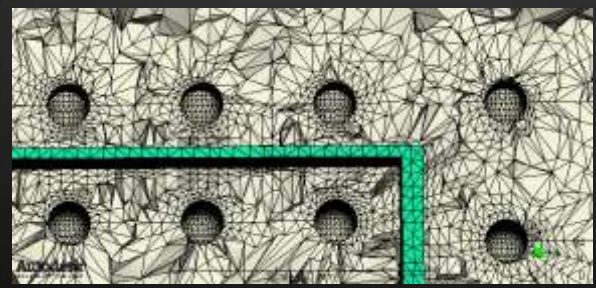
- Temperature of the mold
  - Boundary conditions
    - Heat inflow from the polymer melt, hot runners or heater cartridges
    - Heat outflow to the coolant and outer mold surface
- To solve for the average mold temperature during the cycle:

$$0 = \nabla \cdot (k \nabla T)$$

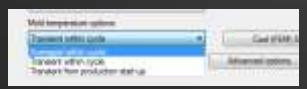
- This is the equation for steady-state heat flow
  - Linear equation
  - Can be solved by the Boundary Element Method
    - Only requires a boundary mesh of the mold

Cool (FEM) ..... with Transient Cool option

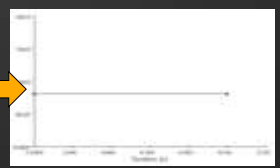
- Volume (tetrahedral) mesh of the mold geometry, can be used to solve the mold temperature equation in either steady-state or with the transient term



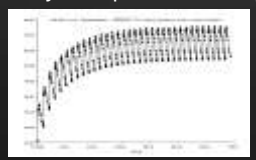
Mold Temperature Analysis Options



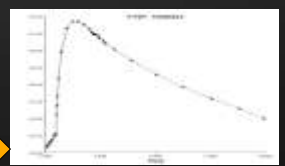
- Average of whole Cycle (Steady-State)
  - Equivalent to standard cool analysis in Insight 2011



- Full transient history from product start-up

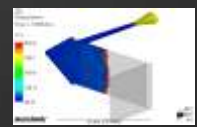


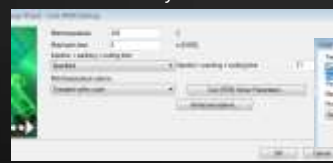
- Transient during a stable molding cycle--→



Two options for Part heat flux calculation

- Full flow analysis at every iteration
  - Includes full effect of shear heating and material convection
- Conduction solver
  - Assumes the cavity is instantly filled at melt temperature
  - Same as used for the conventional (BEM) Cool analysis
  - Much faster analysis



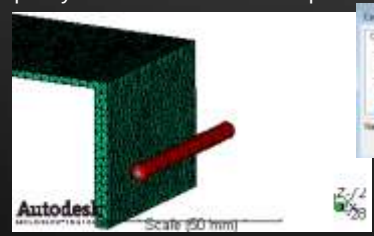


Availability and features

- First commercial release of Cool (FEM) / Transient Cool Autodesk Moldflow Insight® 2012 :
  - Only for 3D Mesh type. i.e. 3D cavity mesh
  - Can use either tetrahedra or beam elements for the feed system
  - Uses beam elements for the circuit flow calculation
  - Can include mold inserts, part inserts and cores
    - (Meshed after import from CAD)
  - Supports heat flux setting from hot runners and cartridges heater

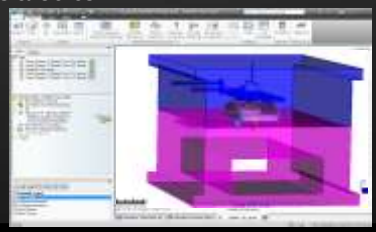
Cartridge Heaters (Moldflow Insight 2012)

- Modelled as beam elements
  - Can be non-circular (rectangular)
- Specify either Heat Flux or Temperature



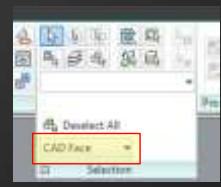
How to prepare the 3D mold mesh (1)

- From CAD geometry of the mold
  - Model the cooling lines, feed system and cavity as features cut out of the mold block
  - Special feature in Autodesk Inventor Professional ® allows the mold geometry to be simplified and exported for Moldflow Cool (FEM) analysis.
- Can include Part Inserts, Mold Inserts & Cores



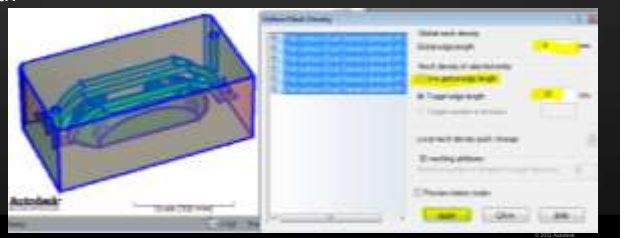
Specifying Mesh Density on CAD Imported Mold

- Change Selection mode to allow CAD Faces to be picked
  - On the “Mesh” Menu
- Select just the outer mold surfaces



Specifying Mesh Density on CAD Imported Mold (2)

- Specify a larger element size on the outer surfaces than the internal (Global) size
- Select all surfaces in the list
- Deselect “Use global edge length”
- Set Target edge length
- Click Apply

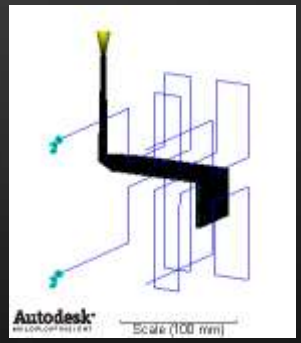


How to prepare the 3D mold mesh (2)

1. Start from an existing Moldflow Insight study file
   - With cavity mesh and cooling circuit lines and feed system lines
2. Use Mold Surface Wizard to define mold size
3. 3D Mold mesh wizard in two stages to build the mold mesh from these features and boundary.

3D Mold Meshing – Detailed Walkthrough (1)

- Start with an existing study file
  - Need a 3D Part mesh
  - Runner system can be tetrahedra or 1D curves
  - Cooling lines must have 1D curves (not just beam elements)
  - If you don’t have the 1D curves you can create them using the beam nodes as end points



3D Mold Meshing – Detailed Walkthrough (2)

- To create straight channel lines, use “Create Line”
  - Pick the existing mesh nodes get the end coordinates
  - Extend cooling channels all the way to the intended mold boundary
- If you have a curved cooling channel without the 1D curve: Create curve by Spline

3D Mold Meshing – Detailed Walkthrough (3)

- Set analysis type to Cool (FEM)
- Create outer mold boundary with the “Mold Surface” Wizard
  - Similar to the existing mold surface wizard for convential cool (BEM)
  - Will create only the mold region – not the triangle surface elements

3D Mold Meshing – Detailed Walkthrough (4)

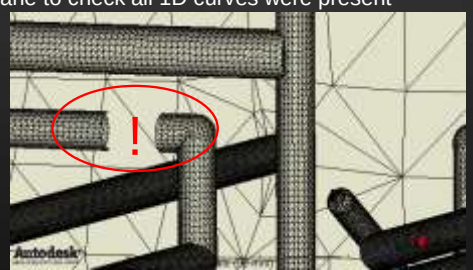
- Launch the 3D Mold Meshing Tool from the study tree (stage 1)

- External: Outer boundary
- Internal: Cavity and Circuits

Recommended ratio: 3 to 4

3D Mold Meshing – Detailed Walkthrough (5)

- Result is a surface mesh on the cavity & feed system, channels and outer boundary
- Use Cutting Plane to check all 1D curves were present

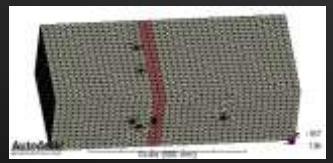


3D Mold Meshing – Detailed Walkthrough (6)

- Launch 3D Mold Meshing again to create tetrahedra (stage 2)

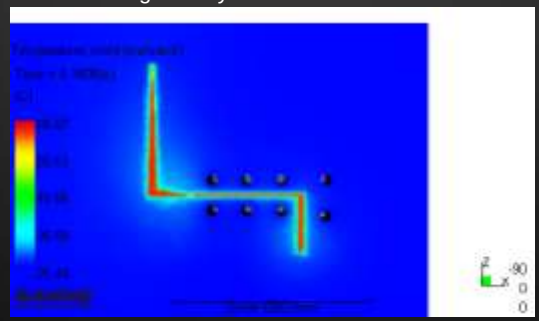
3D Mold Meshing – Detailed Walkthrough (7)

- If you want to see what the internal mold mesh looks like:
  - Put some elements onto a different la
  - Hide all other layers



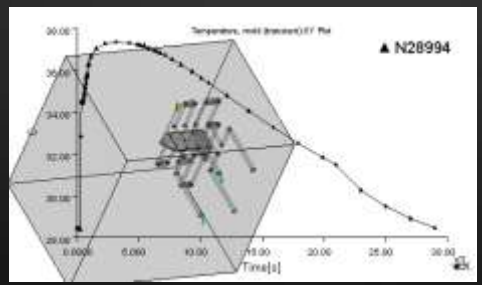
Results: Transient Mold Temperature

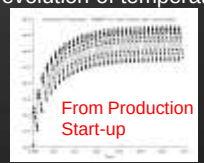
- Can be animated through the cycle



Results: Transient Mold Temperature: XY-Plot

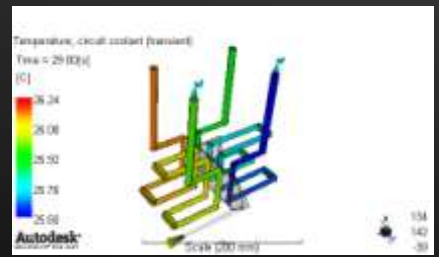
- Select node(s) on the (mold) cavity surface to see the evolution of temperature with time:

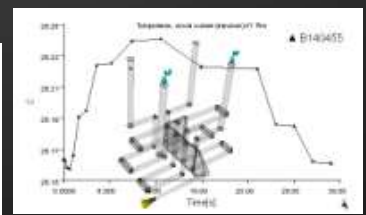




From Production Start-up

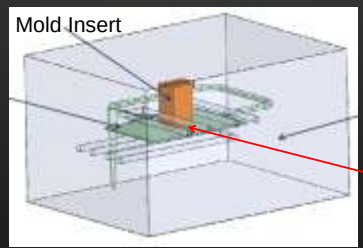
Results: Coolant Temperatures (transient)





Validation: Cethil Mold

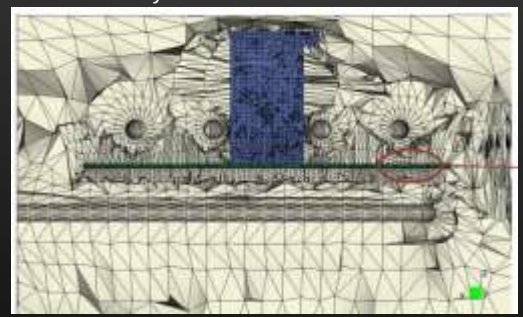
- Molding data received courtesy of Cethil & PEP, France



M. Zinet, Modélisation de la cristallisation des polymères dans les procédés de plasturgie : quantification des effets thermiques et rhéologiques, PhD thesis, Univeristy of Lyon, 2010

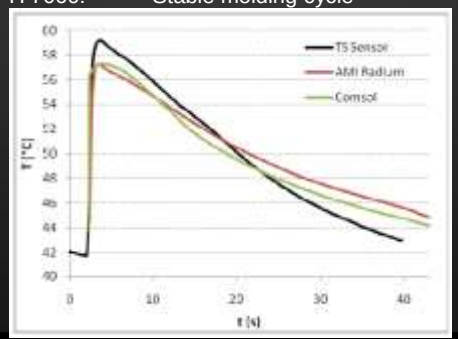
Meshed using Moldflow Insight Mold Meshing

- Part mesh: 4 element layers



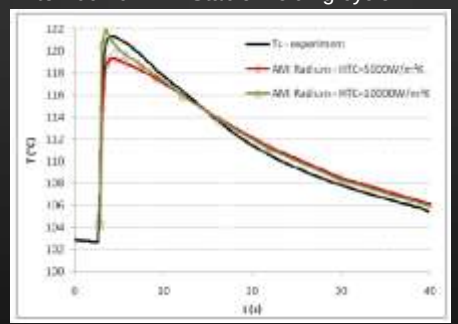
Cethil: Comparison of temperature evolution

- PP – Total PPH 7060: Stable molding cycle



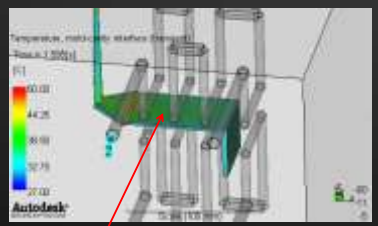
Cethil: Comparison of temperature evolution

- PBT – DSM Arnite T06 202: Stable molding cycle



Validation: Corner Mold: Combo P-T Sensor

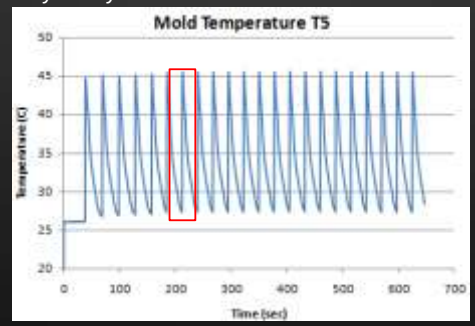
- Molded in the Moldflow Laboratory, Melbourne
- PP unfilled



Sensor Location. Kistler Combined Pressure & Temperature Sensor

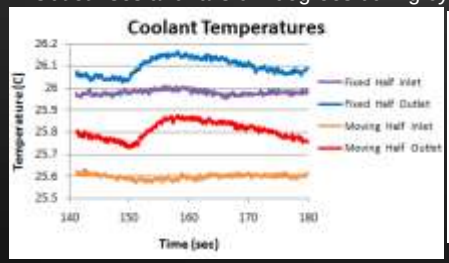
Temperature history from start up: Measured

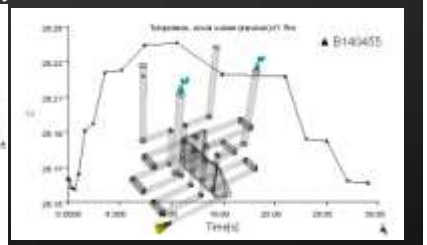
- Stable cycles by 7th Cycle



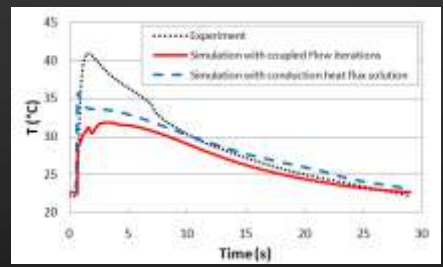
Validation: Coolant Sensors

- Flow rate sensor (x 2 circuits)
- Coolant Temperature Inlet and Outlet (x 2 circuits)
- Outlet rises and falls 0.1 degrees during cycle





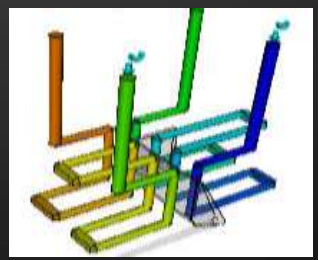
Mold Temperature Profile at Sensor



- Provisional Result – Further investigation required to check why temperature peak is missed in the simulation
- Need to consider effect of sensor insulation?

Transient and Conformal Mold Cooling Simulation

- Review
- Updates in Scandium Tech Preview 2
  - Reactive Molding
  - Dual Domain
- Rapid Heat Cycling
- Enhanced Heater Options
- Mold Meshing Enhancements
- Conformal Cooling



Disclaimer

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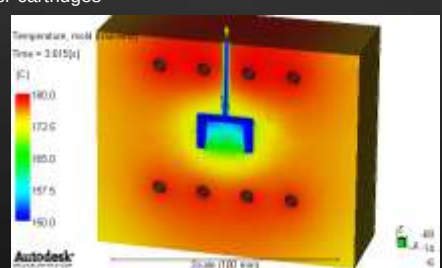
These statements are being made as of today (Nov 29, 2011) and we assume no obligation to update these forward-looking statements to reflect events that occur or circumstances that exist or change after the date on which they were made. If this presentation is reviewed after the date of its original publication, these statements may no longer contain current or accurate information.

Scandiudm Technology Preview 2

- Free download
  - labs.autodesk.com
- English, Windows only
- Requires Autodesk Moldflow Insight 2012 license
- Provides extended features for Cool (FEM) – Transient Cool

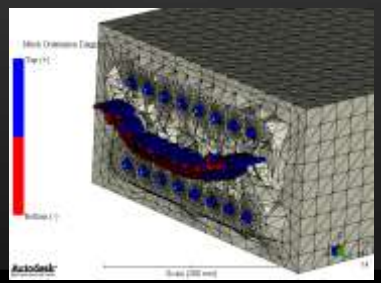
Transient Mold Thermal Analysis for Reactive Molding

- Called “Cool (FEM)”
  - But more typically will involves heating of the resin from the hot mold
  - Hot fluid or heater cartridges



Transient Cool Analysis for Dual-Domain Part meshes

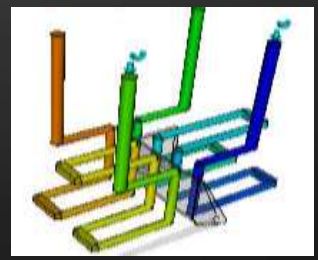
- Support Dual-domain part meshes for Cool (FEM) analysis
  - Mold Mesh is Tetrahedral Elements
  - Not yet transferring the transient mold surface temperatures into the dual-domain flow solution



Can not choose Full Flow on Every Iteration

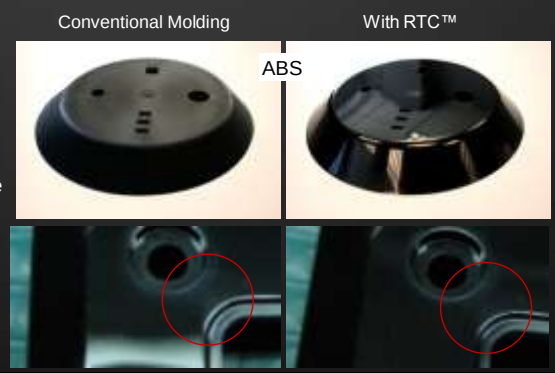
Transient and Conformal Mold Cooling Simulation

- Review
- Updates in Scandium Tech Preview 2
- Rapid Heat Cycling
  - Heating and Cooling Fluids
  - Cycling Timing Controls
  - Parting Plane
  - Case Study
- Enhanced Heater Options
- Mold Meshing Enhancements
- Conformal Cooling



Rapid Temperature Cycling / RHCM ® / Variotherm ®

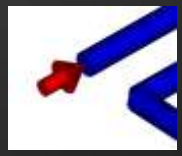
- Heat Mold for Filling
  - Eliminate visible weld-lines
  - Increase flow length
  - High (uniform) gloss finish
  - Eliminate Gate Marks (Cold slugs)
  - Typically only the cavity side is heated
- Heat by: Steam, Electrical or Induction
- Cool Mold during Packing
  - Reduce cycle time

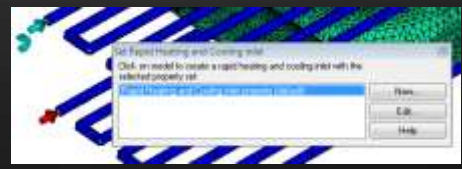


Images courtesy of GasInjection World Wide

Rapid Temperature Cycling / RHCM ® / Variotherm ®

- New Rapid Heating and Cooling property type for cooling channel inlet
- Can only be selected once an analysis sequence containing Cool (FEM) has been selected
  - Not supported by Boundary Element Cool
- Allows specification of:
  - Heating
  - Cooling
  - Timing



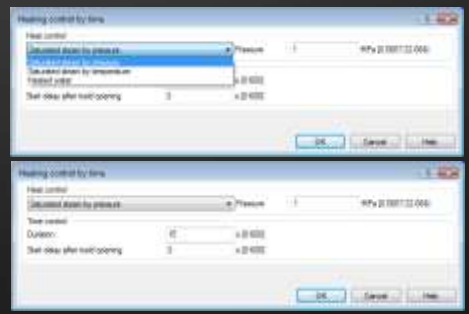


Rapid Temperature Cycle

- Process Cycle
  - Heating Phase
  - Air Purge
  - Cooling Phase
  - Air Purge
- Heating and Cooling phases:
  - Time Controlled, or
  - Temperature (Thermocouple) Controlled

Rapid Temperature Cycle: Heating Phase

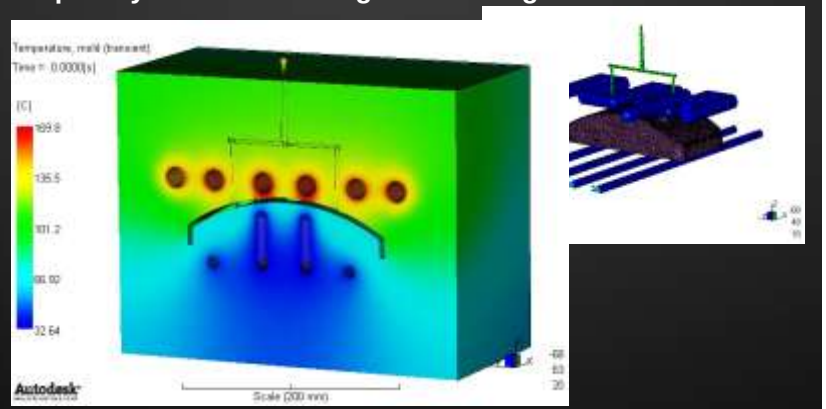
- Heating Fluid
  - Saturated Steam by set Pressure
  - Saturated Steam by set Temperature
  - Heated (pressurized) water
- Timing
  - Duration of Heating fluid flow
  - Start time referenced from mold opening



Rapid Temperature Cycle: Temperature Control

- Heating Phase / Cooling Phase continues until a target temperature is achieved at Thermocouple
  - Specify Thermocouple location by node number
  - Thermocouple would typically be placed near the cavity
- Specify how the cycle control waits until heating is complete
  - Delay mold closing
  - Delay start of Injection
  - Do not delay injection
- Mold opening / ejection will always wait for the cooling phase to be completed

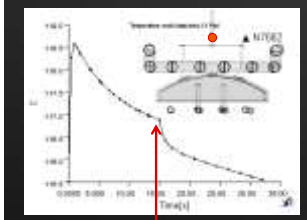
Example: Cyclic Mold Heating and Cooling Result



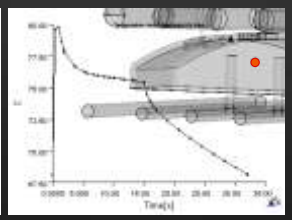
Example: Cyclic Mold Heating and Cooling Result

Mold Temperatures:

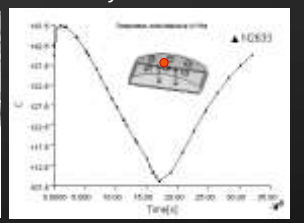
At Sprue surface



On Core-side surface



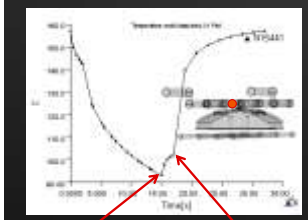
On Cavity-side surface



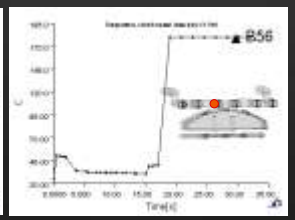
Time of Ejection

Example: Cyclic Mold Heating and Cooling Result

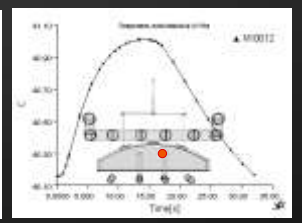
Mold Temperature at Steam/Water channel



Fluid Temperature in Steam/Water channel



Mold Temperature on Bubbler surface

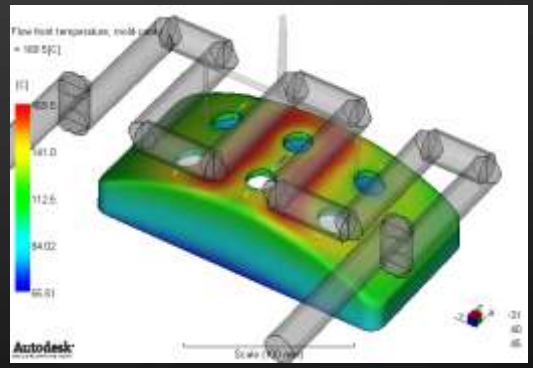


Cooling flow stopped

Steam Heating Start

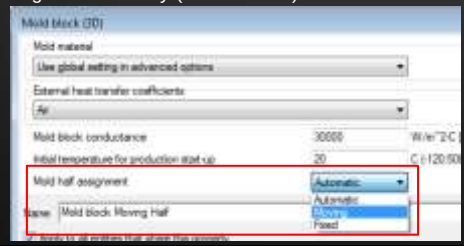
New Result: Flow Front Cavity Surface Temperature

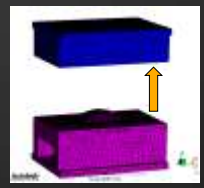
- Cavity surface temperature at the time of filling
  - Useful to understand gloss and weld-line appearance



Thermal Isolation during Mold Open

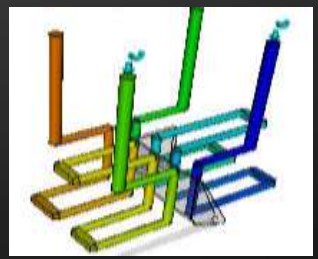
- Rapid heating usually only on cavity side (fixed-side)
- Heating Phase may start while mold is open
  - So do not allow thermal contact between mold halves
  - Assign automatically (Can override)





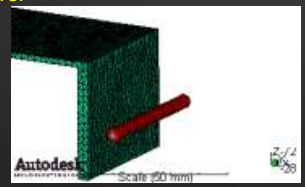
Transient and Conformal Mold Cooling Simulation

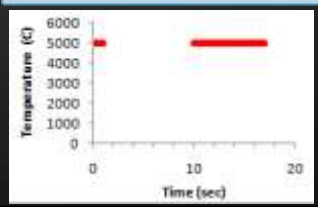
- Review
- Updates in Scandium Tech Preview 2
- Rapid Heat Cycling
- Enhanced Heater Options
  - New Cartridge Heater Controls
  - Hot Runner Heater Elements
- Mold Meshing Enhancements
- Conformal Cooling



Additional Cartridge Heater Controls

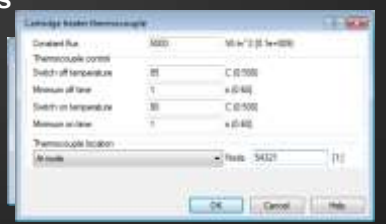
- Time Control

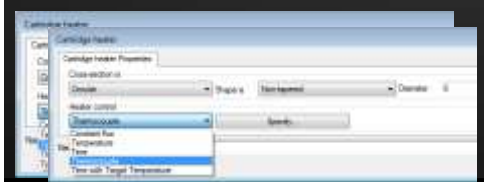


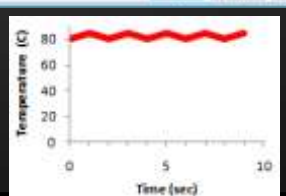


Additional Cartridge Heater Controls

- Time Control
- Thermocouple
  - Switches Heat Flux On/Off to try maintain temperature within set range at a thermocouple

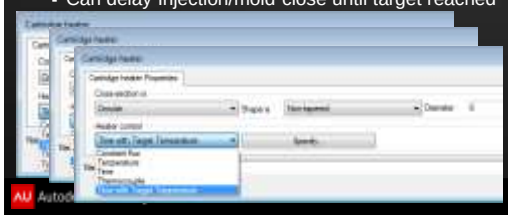


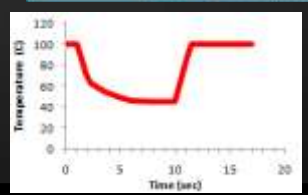




Additional Cartridge Heater Controls

- Time Control
- Thermocouple
  - Switches Heat Flux On/Off to try maintain temperature within set range at a thermocouple
- Time & Target Temperature for RTC
  - Specify On/Off periods in the cycle
  - Specify a target temperature at control node
  - Can delay Injection/mold close until target reached

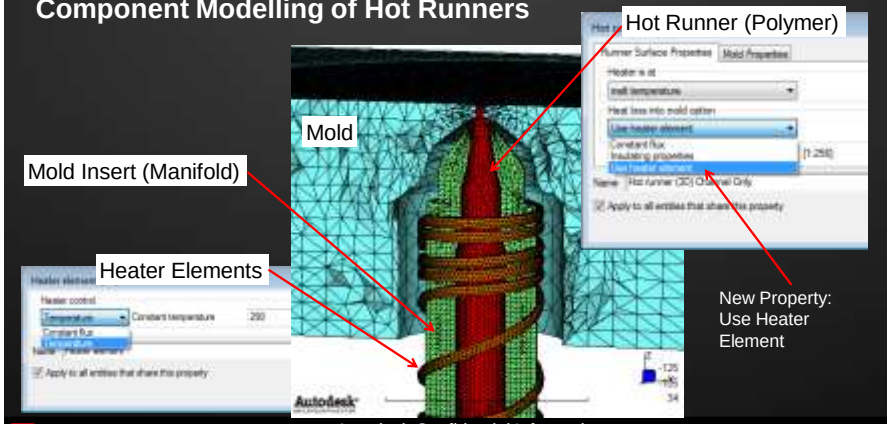




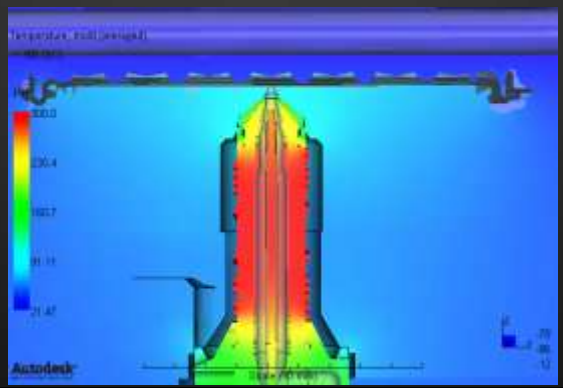
Modelling of Hot Runners

- Currently:
  - Polymers sees set heater temperature
  - Heat Loss into Mold:
    - Fixed flux (Default = 10 W/m^2), or
    - Insulating properties of air gap

Component Modelling of Hot Runners

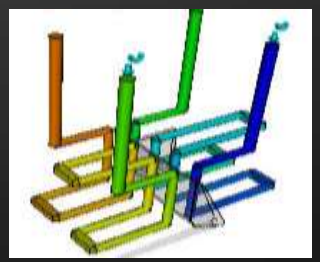


Component Modelling of Hot Runners



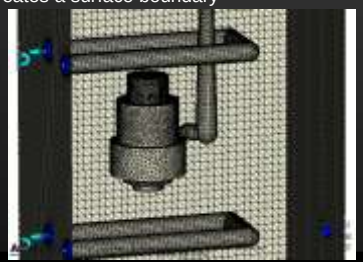
Transient and Conformal Mold Cooling Simulation

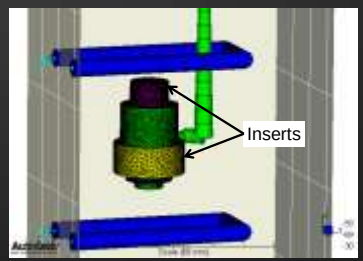
- Review
- Updates in Scandium Tech Preview 2
- Rapid Heat Cycling
- Enhanced Heater Options
- Mold Meshing Enhancements
  - Concept
  - Stitching Tool
- Conformal Cooling



Mold Meshing for Assemblies

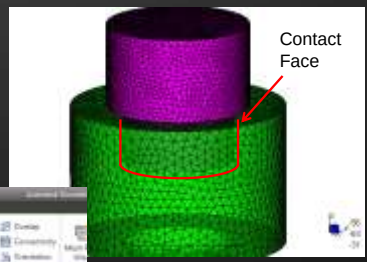
- 3D Mold Meshing Wizard creates mold geometry around part, channels and feed system
  - First creates a surface boundary

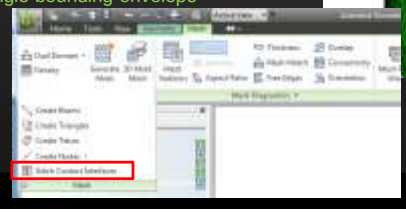




Mold Meshing for Assemblies

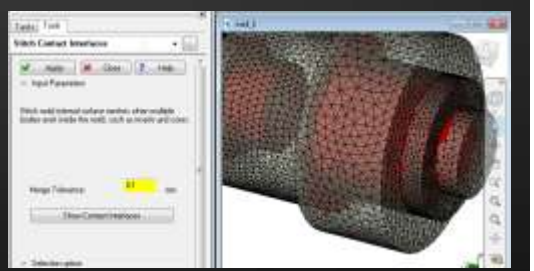
- Insert contact faces would cause a double boundary
  - Not supported in the Autodesk Moldflow Insight 2012 Mold Meshing Wizard
- Stitch together the surface meshes of the cavity and inserts
  - Create a single bounding envelope





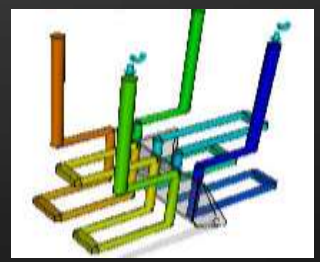
New Surface Stitching Tool

- Use Before launching 3D Mold Meshing
- Works on whatever is visible
- Eliminates contact surfaces
  - Stitches together at boundaries
  - Preview shows contact areas
  - Specify tolerance



Transient and Conformal Mold Cooling Simulation

- Review
- Updates in Scandium Tech Preview 2
- Rapid Heat Cycling
- Enhanced Heater Options
- Mold Meshing Enhancements
- Conformal Cooling
  - General Purpose Boundary Condition
  - Autodesk Simulation CFD



Conformal Cooling

- Complex 3D cooling channels
- Temperature control follows part shape
- May not be suited to simulation with beam elements

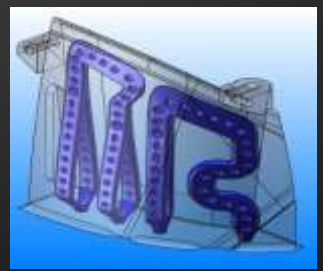
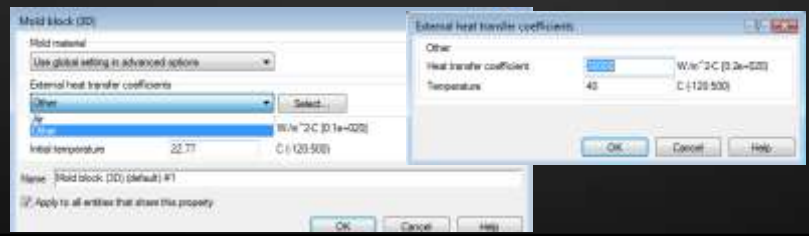


Image from Pôle Européen de Plasturgie

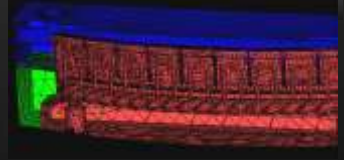
General purpose boundary condition

- External facing mold tetrahedral elements:
  - Default boundary condition is conduction to air
  - By selecting “Other”, any contact condition can be modelled
- This can be used to model complex 3D cooling circuits



Complex 3D Cooling geometry

- Mold Insert with complex cooling channels fabricated by laser sintering
- Mesh each mold component
  - Less than 10 minutes total time
- Analysis:
  - Transient Cool + Flow + Warp
  - 25 minutes (on a Notebook)



Temperature after 1.9s

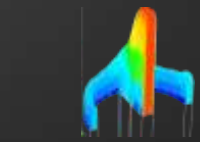
Leveraging Simulation CFD for Transient Conformal Cooling Analyses

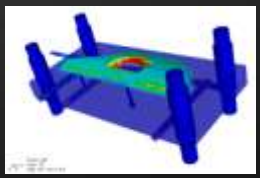
Simulation CFD Background

- Computational Fluid Dynamics = simulating fluid flow and heat transfer numerically
  - Historically very time consuming and difficult
- Hardware advances + 3D modeling + new manufacturing methods
- Virtual prototyping and testing

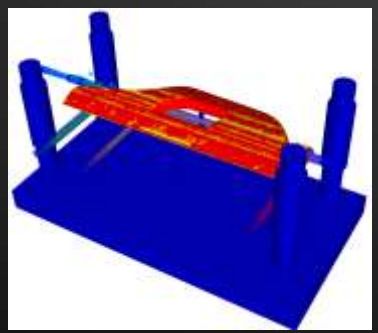
Simulation CFD for Conformal Cooling and Mold Design

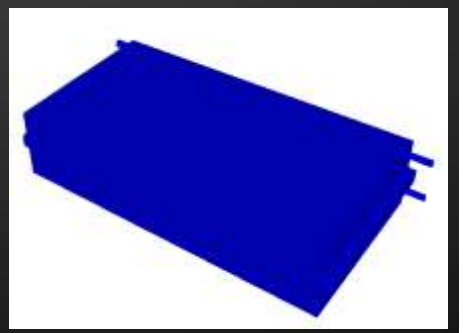
- Allows rapid studies of dramatically different design concepts
- Coolant flow, transient heating and cooling, material response
- Enables state-of-the-art production methods by eliminating or dramatically reducing prototypes:
  - Laser sintering, vacuum brazing, 5-axis drilling





Mold Cooling Transient Response Output

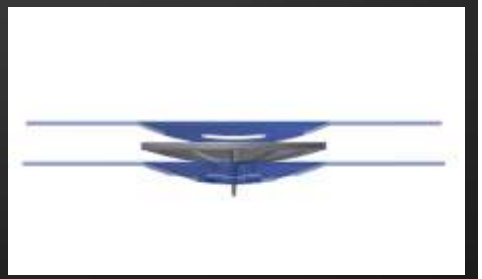




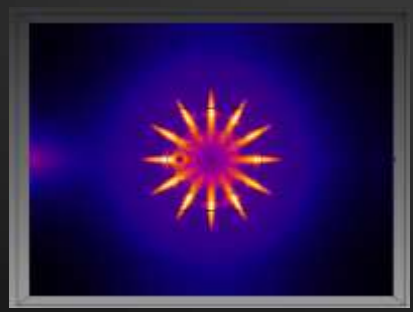
Business Benefits of Digital Prototyping

- Lower Tooling Costs – 20-40%
- Reduce cycle times – up to 30-60%
  - Geometry-dependent – more difficult cooling equates to more time savings
- Faster delivery
- Reduce rework - $100K+
- Gain advantage in competitive industry

Conformal Cooling Example



Simulation CFD Results



Questions & Discussion

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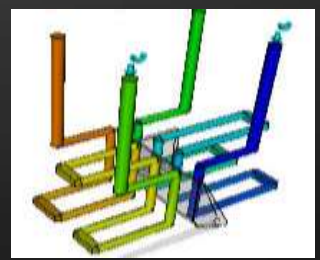
- Mold Meshing Enhancements
- Conformal Cooling



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